The Crucial Role of $\omega\pi^+$ Production in the D_s^+ Decay

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ABSTRACT

In this paper the relevance of non-spectator decays of charm particles is analysed and some crucial tests for it are suggested.

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A longstanding (unsolved) problem in charm decay has been to provide a reliable estimate of non-spectator contributions in the decay of charm particles (in particular of the so-called W-annihilation). In this paper we are going to analyse a number of issues related to this problem in the light of a recent analysis of new data of the E-687 Collaboration [1]:

i) first, we discuss several points connected with the case of three-pion D_s^+ decay and point out that some crucial measurements could allow an uncontroversial assessment of the importance (or of the insignificance) of non-spectator contributions. Specifically, we suggest that a precise measurement of the channel $D_s^+ \to \omega\pi^+$ could cast the final word on the rôle of the W-annihilation non-spectator component in the decay of D_s^+.

ii) Second, we question the importance of the $s\bar{s}$ component in $f_0(980)$, $f_0(1300)$ and $f_2(1270)$.

iii) Next, we propose a specific mechanism that accounts for the absence of $D_s^+ \to \rho^0\pi^+$ (another longstanding problem in the theoretical analysis of D_s^+ decay) and we suggest ways to check it.

iv) Finally, should not the decay $D_s^+ \to \omega\pi^+$ be observed with a significant Branching Ratio (BR), we would have to revise the traditional W-annihilation diagram* and other mechanisms of W-annihilation would have to be invoked to explain some decays that would otherwise be inexplicable. One such possibility will be briefly discussed.

Although the considerations that follow are largely qualitative, we believe that our reasoning is tight enough to make the ensuing scheme self-contained and worth being experimentally investigated and tested.

Recently, an exhaustive experimental analysis of the 3-pion final state decays of the charm pseudoscalar D_s^+ meson has been offered [1] which increases significantly

* By this we mean the mechanism by which the $c\bar{s}$ components of the D_s^+ annihilate into a virtual W^+ which then decays into a pair of on shell quarks which fragment into the final hadrons. Such a diagram is depressed by the helicity conserving W-coupling to quarks.

the existing statistics and consequently sheds considerable light in a very confused picture. In spite of the (still sizeable) error bars, this Dalitz plot analysis modifies considerably the pre-existing situation [2]. The most important conclusion reached in [1] concerns the smallness (in fact, the insignificance) of the *non-resonating* $D_s^+ \to 3\pi$ channel credited previously with a non insignificant BR = $(1.01 \pm 0.35)\%$ [2]. In addition, in this analysis, a) two new channels, $D_s^+ \to f_2(1270)\,\pi^+$ and $D_s^+ \to f_0(1300)\,\pi^+$ have been discovered (admittedly though, the error bars are still quite large), b) the absence of a significant channel $D_s^+ \to \rho^0\,\pi^+$ has been confirmed and, finally, c) the existence of a sizeable BR in the (already observed) channel $D_s^+ \to f_0(980)\,\pi^+$ has been substantiated.

While the observation of a non-resonant three-pion decay would have represented a clear signature in favour of a non-spectator D_s^+ decay, its smallness (compatible with zero [1]), unfortunately, does not convey an equally unambiguous (albeit negative) result. It is, in fact, well known that a relevant component of three-body decays of charmed particles comes from two-body decays in which one of the decay products is in turn a resonant state. Thus, the fact that the non-resonant $D_s^+ \to 3\pi$ channel is very small, confirms simply something that was already known; differently stated, the smallness of a non-resonant three-pion decay channel by itself does not imply the absence of W-annihilation type diagrams in D_s^+ decay.

Quite analogously, the observation of the decay $D_s^+ \to \rho^0\,\pi^+$ would have been a clear signature of a non-spectator diagram. In point of fact, based on the experimental observation of a significant BR for the decay $D^0 \to \bar{K}^0\,\phi$ $[(0.83 \pm 0.12) \times 10^{-2}]$ [2] which denotes a large non-spectator component in D^0 decay, some theoretical models [3, 4] had predicted a large BR for the decay $D_s^+ \to \rho^0\,\pi^+$. This prediction was not met by the data [2] for which the upper limit is BR$[D_s^+ \to \rho^0\,\pi^+]$ $\lesssim 2.8 \times 10^{-3}$.

Again, however, the absence of this channel may have other explanations and does not conclusively exclude the contribution of non-spectator diagrams. To provide an example of how this may come about, let us point out that a possible explanation for such a constraining experimental result could be found in the very

form of the isospin component ρ^0 wave function which is $1/\sqrt{2} \times (u\bar{u} - d\bar{d})$. If, in fact, we assume *factorization* of the $\rho^0\pi^+$ wave function

$$\begin{aligned} \langle \rho^0\,\pi^+ | H_W | D_s^+ \rangle &= \frac{1}{\sqrt{2}}\,\langle (u\bar{u} - d\bar{d})\,(u\bar{d}) | H_W | D_s^+ \rangle \\ &= \frac{1}{\sqrt{2}}\,\left[\langle (u\bar{u})\,(u\bar{d}) | H_W | D_s^+ \rangle - \langle (d\bar{d})(u\bar{d}) | H_W | D_s^+ \rangle \right] \approx 0 \end{aligned} \tag{1}$$

we are led to an immediate explanation for the smallness of this particular decay channel.

This possibility, (which appears extremely natural and had not been taken into account in the afore-mentioned estimates), can easily be checked since it also predicts the absence of other decay channels involving the direct (*i.e. non-resonant*) production of either one π^0 or of one ρ^0 when a factorization analogous to (1) can be performed. Care must be taken, however, be taken; this *no-go* mechanism does not apply when these particles (ρ^0 or π^0) can only be produced from either one, but *not from both* the two $u\bar{u}$ and $d\bar{d}$ configurations. Thus, in order to check experimentally that this mechanism is indeed responsible for the absence of the $\rho^0\pi^+$ final state, we suggest, as an example, that the channel $D_s^+ \to \phi\,\pi^+\,\pi^0$ be investigated. If our conjecture is correct, the BR for this reaction should also be essentially zero. As a matter of fact, this decay channel has not been observed so far.

Assuming now that the previous factorization of the isospin wave function is indeed responsible for the strong suppression of the decay channel $D_s^+ \to \rho^0\,\pi^+$, an immediate test of its validity and, at the same time, of the existence of W-annihilation diagrams can be suggested. The isospin wave function of the $\omega(782)$ being $1/\sqrt{2} \times (u\bar{u} + d\bar{d})$, the decay $D_s^+ \to \omega\,\pi^+$ (which can only proceed via W-annihilation) should *not* be suppressed by the mechanism which we have invoked for the case $D_s^+ \to \rho^0\,\pi^+$.

A (very rough) evaluation of the BR$[D_s^+ \to \omega(782)\,\pi^+]$ can be given by the same argument used originally [4] to estimate $D_s^+ \to \rho^0\,\pi^+$. The form factor involved in the latter is dominated by the $a_1(1260)$ pole while the form factor involved in the decay $D_s^+ \to \omega(782)\,\pi^+$ is dominated by the $b_1(1235)$ pole. Assuming the

various parameters to be comparable and the normalization constant to be of order unity [3, 5], we can expect

$$\mathrm{BR}\,[D_s^+ \to \omega(782)\,\pi^+] \simeq 1\% \tag{2}$$

if our assumption is correct. The experimental data do not provide at the moment any definite answer about the existence of the above decay channel; the present situation offers only a rather large upper bound, $\mathrm{BR}[D_s^+ \to \omega(782)\pi^+] < 1.7\%$ [2]. A careful experimental search of this channel is highly necessary since it appears to be a crucial test to prove or disprove the existence of non-spectator contributions in D_s^+ decay.

The observation, with a BR of the order of 1% as suggested in Eq. (2), of the $D_s^+ \to \omega(782)\,\pi^+$ decay mode, would be a strong argument in favour both of a sizeable W-annihilation contribution and of the wave function factorization argument, Eq. (1). In such a case other decay channels which can only (or mainly) proceed through W-annihilation should be observed with comparable branching ratios. On the other hand, the non observation of this decay (or a very tiny BR $\ll$ 1%), would definitely exclude a relevant contribution from the usual W-annihilation decay mechanism; in this case, other mechanisms should be responsible for the observation of decays which could have occurred via simple W-annihilation; one such possibility will be discussed shortly.

Let us recall once again that the new data [1] indicate that the decay $D_s^+ \to 3\pi$ proceeds mainly through the resonant channels $D_s^+ \to R\pi^+$ (with $R = f_0(980)$, $f_0(1300)$ and $f_2(1270)$). According to the quark model, these resonances are classified as isospin singlets with different mixtures of $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$ components, whose exact nature is still much debated [6]. A precise knowledge of their quark content is of the greatest importance to understand the relevance of non-spectator contributions in the decay $D_s^+ \to 3\pi$. The presence of a dominant $s\bar{s}$ component (as in the case of the $f_0(980)$), suggests that the $D_s^+ \to f_0(980)\pi^+$ decay should occur through a spectator process; on the other hand a negligible $s\bar{s}$ component (which seems to be the case for $f_2(1270)$ and $f_0(1300)$), would rather point to a non-spectator decay.

Let us consider separately the $f_0(980)$ and the $f_2(1270)$, $f_0(1300)$ resonances. The first one, which contributes the largest part of the $D_s^+ \to 3\pi$ decay rate, is well known to have a large branching ratio into $K\bar{K}$ strange mesons, BR[$f_0(980) \to K\bar{K} = (21.9 \pm 2.4)\%$] [2]. Considering the tiny phase space available for such a reaction it is natural to expect the $f_0(980)$ to be dominated by a $s\bar{s}$ quark component. As a consequence, the decay $D_s^+ \to f_0(980)\pi^+$ is most certainly occurring via a dominant spectator diagram.

For the other two resonances which also have been observed in the $D_s^+ \to 3\pi$ channel the situation is quite different: despite a larger phase space available, their branching ratios for decays into strange mesons are much smaller [2]: BR[$f_2(1270) \to K\bar{K} = (4.6 \pm 0.5)\%$] and BR[$f_0(1300) \to K\bar{K} = (7.5 \pm 0.9)\%$]. Both values are similar to those observed for the decays into strange mesons of particles whose $s\bar{s}$ component is known to be essentially zero, like $a_2(1320)$, $\pi_2(1670)$ and $\rho_3(1690)$, for which, typically, BR $\sim 5\%$. This strongly suggests that the $s\bar{s}$ content of $f_2(1270)$ and $f_0(1300)$ is negligible. The same conclusion about the strange component of $f_0(980)$ and $f_0(1300)$ has been reached in Ref. [7].

A dominant $u\bar{u}$ and $d\bar{d}$ component of the $f_2(1270)$ and the $f_0(1300)$ implies that the observed decays $D_s^+ \to f_2(1270)\pi^+$ and $D_s^+ \to f_0(1300)\pi^+$ cannot occur through the spectator diagram of W-radiation, but should rather proceed via the non-spectator diagram of W-annihilation. As already discussed, the relevance of this mechanism would definitely be confirmed by the experimental observation of the decay $D_s^+ \to \omega(782)\pi^+$; a branching ratio of the order of magnitude predicted by Eq. (2), would be a clear signature in favour of the significance of the W-annihilation mechanism and the usual non-spectator models could explain all of these three decays.

In the opposite case – the non observation of a sizeable branching ratio for the $D_s^+ \to \omega(782)\pi^+$ decay – there is no reason to expect that if the W-annihilation mechanism does not work for the ω vector meson it should work for the scalar or tensor ones, but one should rather accept the usual helicity argument which forbids simple W-annihilation. In this case, one would have to look for different decay diagrams to account for the $D_s^+ \to f_2(1270)\pi^+$ and $D_s^+ \to f_0(1300)\pi^+$ modes.

These new diagrams should allow the production of scalar and tensor particles while forbidding that of vector ones (like ρ^0 and ω).

An interesting possibility is shown in Fig. 1, according to which the c and $\bar{s}$ quarks in the D_s^+ not only annihilate into a virtual W^+, which directly generates the π^+, but also into two gluons; this avoids the helicity argument [8, 9]. For such a contribution to be significant the two gluons must couple directly to a large gluon component of the final meson: f_0 and f_2 have the right quantum numbers and could indeed be produced via this scheme, but a 1^{--} vector meson state could not be produced owing to the positive C-parity of a two gluon state.

This mechanism is similar to the one suggested previously to explain the decays $J/\psi \to \rho\pi$ [10] and $\eta_c \to VV$ [11] (where V is a vector meson). These processes have in fact posed a challenge in their theoretical interpretation; although forbidden by helicity conservation, they have been known to occur for a long time and are observed with significant branching ratios of order 1% [2]. The reason why the helicity conservation argument is overcome by the higher order diagram of Fig. 1 lies in the fact that this diagram enhances the production of a resonant $\pi^+\pi^-$ state with an invariant mass M via a Breit-Wigner factor

$$\frac{1}{(M - M_G)^2 + \Gamma_G^2/4}\,, \tag{3}$$

where M_G and Γ_G are respectively the mass and the width of the gluonic state mixed with the $f_2(1270)$ or the $f_0(1300)$.

While, to the best of our knowledge, no other mechanisms have been successful in predicting a significant BR for the reactions $J/\psi \to \rho\pi$ and $\eta_c \to VV$ (explaining, at the same time, the non observation of the $\psi' \to \rho\pi$ decay) the final word on the validity of the mechanism under discussion [10, 11] has still to be said. The intriguing possibility that a similar mechanism may be at the root of the production of $f_2(1270)$ and $f_0(1300)$ in D_s^+ decay leaves us one more chance of explaining these reactions, should indeed the direct W-annihilation be proved absent *i.e.* should the search of a significant $D_s^+ \to \omega(782)\pi^+$ decay be unsuccessful. The mechanism of Fig. 1, however, demands a large coupling to gluons of both $f_2(1270)$ and $f_0(1300)$

which at this stage of our knowledge is neither excluded nor suggested by the data; this in itself raises questions that deserve a careful investigation.

A detailed study of the D_s^+ decay modes will no doubt help in clarifying a very complex situation; here we have just considered in a somewhat limited and qualitative way the rôle of the annihilation $c\bar{s} \to W^+$ in non-spectator decays of D_s^+ and we have raised a number of questions and suggested a number of experimental tests and investigations which could provide a much better insight into these problems. Some conclusions can be safely reached: the observation of the $D_s^+ \to \omega\pi^+$ decay mode with a branching ratio $\sim 1\%$ would definitely prove the relevance of the traditional simple W-annihilation contribution; the observation of a small BR$[D_s^+ \to \omega\pi^+] \ll 1\%$ instead, would indicate a negligible W-annihilation contribution and would pose the problem of explaining some other decays which are so far believed to occur through $c\bar{s}$ annihilation. Alternative mechanisms can be at work in this case and we have suggested one. The solution of these problems opens new interesting possibilities which we hope will soon be investigated experimentally.

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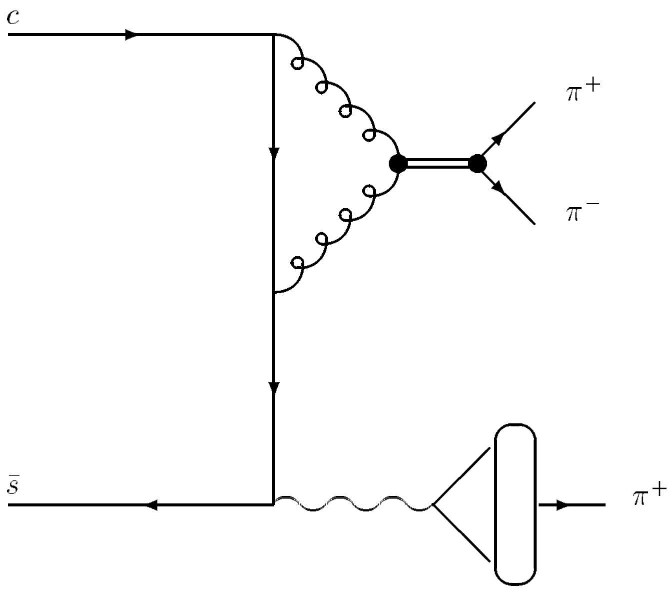

Fig. 1 - Diagram explaining the decay $D_s^+ \to \pi^+\pi^-\pi^+$ through a resonant state coupling to two gluons